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RADIATION EXPOSURE OF LDEF: INITIAL RESULTS

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ABSTRACT

Initial results from LDEF include radiation detector measurements from four experiments, P0006, P0004, M0004 and A0015. The detectors were located on both the leading and trailing edges of the orbiter and also at the Earthside end. This allowed the directional dependence of the incoming radiation to be measured. Total absorbed doses from thermoluminescent detectors (TLDs) verified the predicted spatial east-west dose ratio dependence of a factor $\sim$2.5, due to trapped proton anisotropy in the South Atlantic Anomaly (SAA). On the trailing edge of the orbiter a range of doses from 6.64 to 2.91 Gy were measured under Al equivalent shielding of 0.42 to 1.11 g/cm^2. A second set of detectors near this location yielded doses of 6.48 to 2.66 Gy under Al equivalent shielding of 0.48 to 15.4 g/cm^2. On the leading edge doses of 2.58 to 2.10 Gy were found under Al equivalent shielding of 1.37 to 2.90 g/cm^2. Initial charged particle LET (linear energy transfer) spectra, fluxes, doses and dose equivalents, for LET in $H_2O \geqslant 8$ keV/μ m, have been measured with plastic nuclear track detectors (PNTDs) located in two experiments. Also preliminary data on low energy neutrons were obtained from detectors containing ^{6}LiF foils.

INTRODUCTION

The LDEF orbiter carried four experiments which contained passive integrating detectors from the University of San Francisco. The P0006 LET Spectra Measurements experiment consisted of a single canister in Tray F-2 in which TLDs, PNTDs and neutron detectors were included. The P0004 Seeds in Space experiment consisted of seven canisters in Tray F-2 in which packets containing TLDs, PNTDs and neutron detectors were distributed within the seed component. The M0004 Radiation Effects in Electronics experiment included two detector canisters in Tray F-8 containing TLDs and PNTDs. The A0015 Biostack experiment consisted of two USF (Tray C-2 and G-1-2) and one partial USF (Tray F-2) canisters containing TLDs, PNTDs and neutron detectors.

The purpose of the detectors was to define the radiation environment as a function of shielding depth at the experimental sites on the orbiter. As seen from the Tray locations P0006, P0004 and two A0015 canisters were near the trailing edge. The third A0015 canister was at the earth end while M0004 was at the leading edge.

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EXPERIMENTAL PROCEDURES

The passive radiation detectors were arrayed in stacks within the LDEF flight canisters. All the canisters (except the one partial A0015 unit) were sealed with O-rings to prevent venting to space. The placement of the different detector types was made to enable measurements to be made as a function of shielding depth.

TLD Procedures

Single batches of TLD - 700 were divided into flight, calibration and background portions. The calibration TLDs were irradiated with a standard ^{137}Cs source at two-month intervals over the 5.7 year orbital period in order to approximate both the LDEF absorbed doses and any signal fading which might occur. A high-dose TLD response supralinearity study was also conducted with ^{137}Cs standard doses up to 100 Gy.

After the mission TLDs were read out with a model 4000 Harshaw reader. Calibration and backgrounds were read out along with the flight detectors. The measured signals, averaged over a series of mission TLDs, were then converted to absorbed doses (^{137}Cs gamma ray equivalent). The minimum vertical shielding between each series of TLDs and space was measured and the shielding materials converted into the equivalent mass thickness of Al.

PNTD Procedures

The five types of PNTDs included on the LDEF experiments were pure CR-39, CR-39 with DOP plasticizer, Tuffak and Sheffield polycarbonates and Melinex polyester. Some of the CR-39 has been processed and read out to yield particle flux, dose rate and dose equivalent rate for $LET_{\infty} \cdot H_2O \geqslant 8$ keV/μm.

The CR-39 was processed in 6.25N NaOH solution at 50°C for 36 or 48 hr. After processing pairs of CR-39 layers from the flight stacks were reassembled in their original configurations. The pairs were scanned at the inner, adjacent surfaces under an optical microscope. Coincident track pairs were located in the adjacent surfaces (#2 and #3), then surfaces #1 and #4 were examined to determine whether the particle was of long range (it penetrated both CR-39 layers and resulted in four aligned tracks) or short range (it penetrated only the adjacent surfaces or the adjacent surfaces and one outer surface, resulting in two or three aligned tracks). The long range particles were classified as galactic cosmic rays (GCRs) and also included projectile fragments. The short range (SR) tracks are mainly stopping primary protons and secondary particles deriving from target nuclei within the PNTDs. Because of their short registration ranges protons are classified as SR particles.

The detected track parameters were measured at the #2 surface to determine particle LET. The semimajor and semiminor axes of the elliptical track surface openings were measured with an electronic micrometer. With the PNTD bulk etch and the LET calibration curve for the detectors, the track measurements were converted to LET spectra.

Low Energy Neutron Detectors (LENDs)

The LENDs were composed of ^{6}LiF radiation foils and CR-39 PNTDs. Alpha particles from the $^{6}Li(n,\alpha)T$ reaction were emitted from the foils and detected in the CR-39. The LENDs were exposed in pairs with one detector covered by Gd foils. This allowed the separation of the neutrons into thermal (< 0.2 eV) and resonance (0.2eV - 1MeV) energy regions.

The CR-39 PNTDs were processed in 6.25N NaOH solution at 70° C for 1.25 hours. The alpha particle track densities on the PNTDs were counted manually at 430 x under an optical microscope. The backs of the detectors were also counted to provide the backgrounds due to other charged particle sources present in space. The track densities were converted to neutron fluences and dose equivalents by previously established calibrations. The dose equivalent conversion factors (ref. 1) incorporated QF values of 2 for thermal neutrons and 6.4 for resonance neutrons.

MEASUREMENTS

TLD Results

The TLD measurements from experiments P0006, P0004, M0004 and A0015 are given in Tables I, II, III and IV respectively. The trailing edge TLDs (P0006, P0004) are seen to measure higher dose rates than the leading edge (M0004) and earthside (A0015) TLDs, although the shieldings are somewhat different for the maximum dose rate.

PNTD Results

Measurements of LET spectra from the leading and trailing edges of the orbiter are shown in Figures 1 and 2, respectively. Integral particle flux is plotted against LET_{∞} in H_2O for the Total, GCR and SR particles. Integral flux, dose rate and dose equivalent rate from these measurements are given in Tables V and VI, respectively. In comparing the spectra it is seen that the M0004 (leading edge) curve is much steeper than that of P0006. M0004 has a higher total integrated flux but a smaller flux in the LET region above ~ 12 keV/μ m. The greater importance of high LET particles in contributing dose and dose equivalent can be seen by comparing Tables V and VI, where the P0006 spectrum leads to higher dose rates and considerably higher dose equivalent rates. The differences in the spectra in the two experiments are due both to the position of the experiment on the orbiter and to the considerably different shielding depths. Note that the GCR spectra are truncated, and also perhaps under-measured, due to the difficulty in discriminating between GCR and SR particle tracks in the very high track densities found on the LDEF PNTDs.

LEND Results

Measurements of the low energy neutrons from the trailing edge of the orbiter are given in Tables VII and VIII. The P0004 (Table VIII) fluences and dose equivalents are larger than those in P0006 (Table VII). The P0004 detectors

were surrounded by a greater mass of hydrogenous material (seeds) which contributed to the moderation of high energy neutrons. The two P0004 measurements also have significant variations. The LENDs were located in two different canisters with that in #3 having higher neutron levels than that in #6. From Table II it is seen that the TLDs in mid #6 yielded higher doses than those in mid #3. There was probably a shielding difference from the side for the two canisters.

CONCLUSIONS

Radiation measurements have been made at different positions and shielding depths on the LDEF orbiter. Total absorbed doses measured with TLDs ranged from 6.64 to 2.66 Gy, for shielding of 0.42 and 15.4 g/cm^2, at the trailing edge to 2.58 to 2.10 Gy, for shielding of 1.37 and 2.90 g/cm^2, at the leading edge. This difference reflects the East-West anisotropy of trapped protons at the South Atlantic Anomaly. For heavy particle measurements with PNTDs ($LET_{\infty}H_2O \geqslant 8$ keV/μ m) absorbed doses of 19 and 31 mGy were found at the leading and trailing edges. The shielding at the two positions was 2.74 and 8.88 g/cm^2, respectively. The corresponding dose equivalents were 124 and 328 mSv. Neutron detectors at the trailing edge measured from 0.12 to 0.82 mSv for thermal neutrons and from 7.0 to 14.2 mSv for resonance neutrons. The shielding varied from 16.8 to 6.1 g/cm^2 for the extremes. Further information on charged particle measurements being performed with the LDEF detectors is given by Csige et al (ref. 2).

The preliminary measurements have revealed some of the differences in radiation levels over the surface of the LDEF orbiter and with shielding depth. Future measurements will allow the development of a more comprehensive picture of the quantities and of directional radiation variations.

REFERENCES

1. NCRP Report No. 38, NCRP, Washington D.C., 1971.

2. Csige, I; Benton, E. V.; Frank, A. L.; Frigo, L. A.; Benton, E. R.; Parnell, T. A. and Watts, J. W. Jr.: Charged Particle LET-Spectra Measurements Aboard LDEF, First LDEF Post-Retrieval Symposium, NASA CP-3134, 1992.

TABLE I

P0006: LDEF ABSORBED DOSE MEASUREMENTS WITH TLD-700

TLD Plate No.	Tissue Absorbed Dose (Gy)	Dose Rate (mGy/d)	Al Equivalent Shielding (g/cm^2)
1	6.48 ± 0.24	3.07 ± 0.11	0.48
2	3.92 ± 0.21	1.85 ± 0.10	4.10
3	3.16 ± 0.15	1.49 ± 0.07	8.34
4	2.76 ± 0.13	1.31 ± 0.06	12.2
5	2.66 ± 0.12	1.26 ± 0.06	15.4

The doses were approximately uniform over Plates 1 and 2 and were non-uniform over Plates 3, 4 and 5 (due to lesser shielding through the sides than through the top of the detector assembly for the deeper TLD plates). The minimum shielding to the side (for only the detector assembly) of the individual TLDs was 1.96 to 6.66 g/cm^2 Al equivalent. All shielding was converted to Al equivalent on the basis of the relative ranges of 100 MeV protons in the materials.

TABLE II

P0004: LDEF ABSORBED DOSE MEASUREMENTS WITH TLD-700

Detector No.	Canister No.	Tissue Absorbed Dose (Gy)	Dose Rate (mGy/d)	Al Equivalent Shielding (g/cm^2)
1	6	6.64 ± 0.29	3.14 ± 0.14	0.42
2	6	2.91 ± 0.07	1.38 ± 0.03	11.1
3	6	3.88 ± 0.22	1.83 ± 0.10	~5
4	4	3.12 ± 0.08	1.48 ± 0.04	6.11
5	2	3.05 ± 0.08	1.44 ± 0.04	6.10
6	5	3.09 ± 0.08	1.46 ± 0.04	6.10
7	7	2.93 ± 0.10	1.39 ± 0.05	6.10
8	3	3.15 ± 0.08	1.49 ± 0.05	6.10
GC1		$3.2\pm0.2\times10^{-3}$	1.3×10^{-3}*	
GC2		$3.2\pm0.2\times10^{-3}$	1.3×10^{-3}*	

* For a total detector assembly time of 2418 days. The flight detectors are averaged over the LDEF orbital duration of 2115 days.

The minimum shielding to the side (for only the detector assembly) of the individual TLDs was ~12.4 g/cm^2 Al equivalent. All shielding was converted to Al equivalent on the basis of the relative ranges of 100 MeV protons in the materials. The proton range in the seed was assumed to be equal (in units of g/cm^2) to that of polycarbonate plastic.

TABLE III

M0004: LDEF ABSORBED DOSE MEASUREMENTS WITH TLD-700

Detector No.	TLD Plate No.	Tissue Absorbed Dose (Gy)	Dose Rate (mGy/d)	Al Equivalent Shielding (g/cm^2)
1	1	2.10 ± 0.13	0.99 ± 0.06	2.90
	2	2.37 ± 0.10	1.12 ± 0.05	1.37
2	1	2.19 ± 0.12	1.04 ± 0.06	2.90
	2	2.58 ± 0.09	1.22 ± 0.04	1.37
3(GC)	1	$2.9\pm0.2\times10^{-3}$	$1.3\pm0.1\times10^{-3}$*	
	2	$3.2\pm0.2\times10^{-3}$	$1.4\pm0.1\times10^{-3}$*	
4(GC)	1	$2.9\pm0.2\times10^{-3}$	$1.3\pm0.1\times10^{-3}$*	
	2	$2.9\pm0.2\times10^{-3}$	$1.3\pm0.1\times10^{-3}$*	

* For a total detector assembly time of 2271 days. The flight detectors are averaged over the LDEF orbital duration of 2115 days.

All shielding materials were converted to Al equivalent on the basis of the relative ranges of 100 MeV protons in the materials.

TABLE IV

A0015: LDEF ABSORBED DOSE MEASUREMENTS WITH TLD-700

Canister No.	TLD Plate No.	Tissue Absorbed Dose (Gy)	Dose Rate (mGy/d)	Al Equivalent Shielding (g/cm^2)
1	1	3.93 ± 0.08	1.86 ± 0.04	1.66
	2	2.74 ± 0.23	1.30 ± 0.11	6.23
	3	2.41 ± 0.18	1.14 ± 0.09	10.0
2	1	4.49 ± 0.11	2.12 ± 0.05	3.85
	2	3.29 ± 0.22	1.56 ± 0.10	7.83
	3	3.04 ± 0.32	1.44 ± 0.15	11.7
3	1	3.47 ± 0.22	1.64 ± 0.10	---

Canister #1 was to Earthside.
Canister #2 was at the trailing edge.
Canister #3 was vented to space and at the trailing edge.

Minimum shielding to the side (for only the detector assembly) of the individual TLDs was 2.52 to 5.31 g/cm^2 Al equivalent.

All shielding materials were converted to Al equivalent on the basis of the relative ranges of 100 MeV protons in the materials.

TABLE V. PNTD MEASUREMENTS FROM M0004 (7-1C-1, 2)

	Flux ($cm^{-2} \cdot s^{-1} \cdot sr^{-1}$)	Dose rate ($\mu Gy\ d^{-1}$)	Dose equiv. rate ($\mu Sv\ d^{-1}$)
TOTAL	2.847×10^{-4}	9.09	58.8
GCR	6.322×10^{-6}	0.47	5.0
SR	2.784×10^{-4}	8.62	53.8

$LET_{\infty} \cdot H_2O \geq 8$ keV/μm
Minimum shielding was 2.74 g/cm^2 Al equivalent

TABLE VI. PNTD MEASUREMENTS ON P0006 (7-119, 120)

	Flux ($cm^{-2} \cdot s^{-1} \cdot sr^{-1}$)	Dose rate ($\mu Gy\ d^{-1}$)	Dose equiv. rate ($\mu Sv\ d^{-1}$)
TOTAL	2.526×10^{-4}	14.8	155
GCR	7.980×10^{-6}	1.15	17.0
SR	2.446×10^{-4}	13.6	138

$LET_{\infty} \cdot H_2O \geq 8$ keV/μm
Minimum shielding was 8.88 g/cm^2 Al equivalent

Table VII. Thermal and Resonance
Neutron Measurements for P0006

Neutron Energy Range	Fluence (cm^{-2})	Dose Equivalent (mSv)	Dose Equivalent rate (μSvd^{-1})
$\leqslant$ 0.2 eV	$1.22 \pm 0.24 \times 10^{7}$	0.124 ± 0.024	0.059 ± 0.011
0.2 eV - 1 MeV	$1.43 \pm 0.72 \times 10^{8}$	7.0 ± 3.5	3.3 ± 1.6

Minimum shielding above the detector was 16.8 g/cm^2 Al equivalent. To the side it was 3.3 g/cm^2 plus shielding external to the canister.

Table VIII. Thermal and Resonance
Neutron Measurements for P0004

Canister #	Neutron Energy Range	Fluence (cm^{-2})	Dose Equivalent (mSv)	Dose Equivalent Rate (μSvd^{-1})
3	$\leqslant$ 0.2 eV	$8.1 \pm 1.6 \times 10^{7}$	0.82 ± 0.16	0.38 ± 0.07
	0.2 eV - 1 MeV	$2.9 \pm 1.4 \times 10^{8}$	14.2 ± 7.1	6.7 ± 3.4
6	$\leqslant$ 0.2 eV	$4.0 \pm 0.8 \times 10^{7}$	0.41 ± 0.08	0.19 ± 0.04
	0.2 eV - 1 MeV	$1.9 \pm 0.9 \times 10^{8}$	9.2 ± 4.6	4.3 ± 2.2

Minimum shielding above the detector was 6.1 g/cm^2 Al equivalent. To the side it was approximately 12.4 g/cm^2 plus shielding external to the canister.

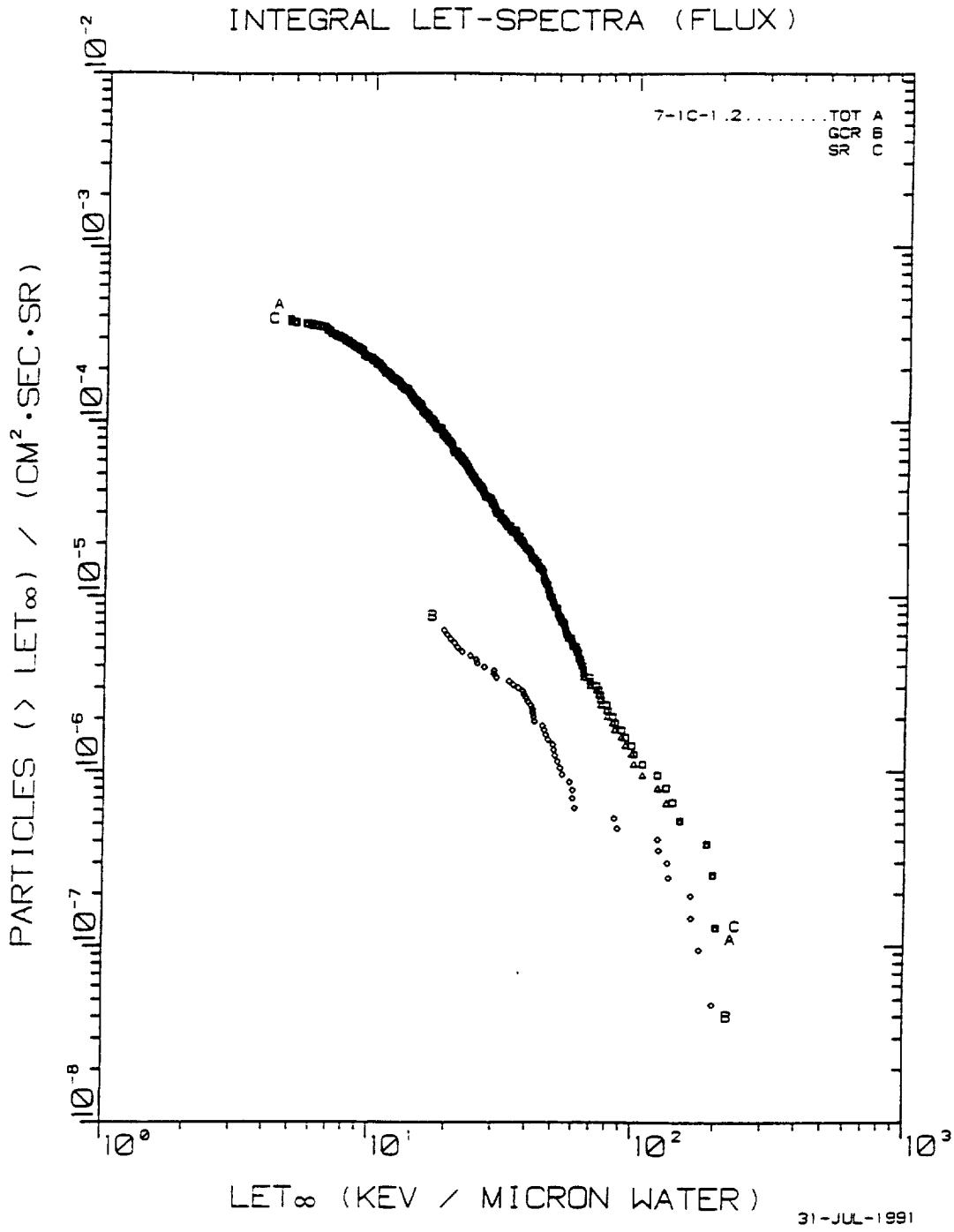


Fig. 1 Integral LET flux spectra from the M0004 experiment on the leading edge of the orbiter. The minimum shielding was 2.74 g/cm² Al equivalent.

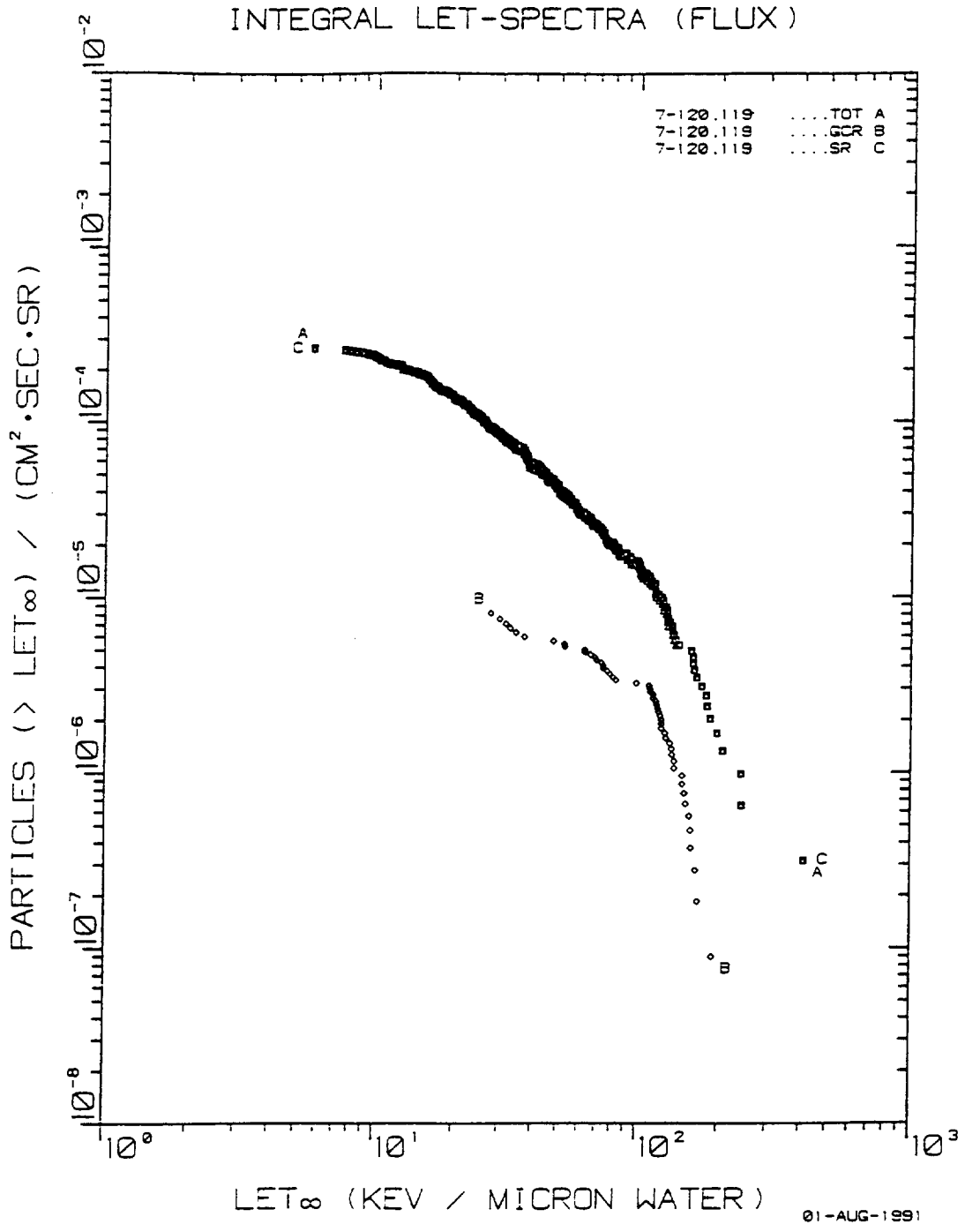


Fig. 2 Integral LET flux spectra from the P0006 experiment on the trailing edge of the orbiter. The minimum shielding was 8.88 g/cm² Al equivalent.